HYPNOPAEDIA: A STUDY OF THE ABILITY TO LEARN WHILE SLEEPING

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Part I: Personal Section

Since middle school, I have been interested in cognition research. My first study of the topic of cognition was on the possibility that eye charts unintentionally test familiarity with the letters being used, as well as a subject's vision. I did this project in 8th grade. My research concluded that eye charts do test familiarity with the English letters being used in addition to testing vision, and should be changed to more directly test vision without testing recognition, as those who are not as familiar with the English alphabet would be at a disadvantage. In high school I did some minor research mostly on brain cognition with relation to object recognition for three years. I decided that I was ready for actual lab experience in the field of cognition. Last spring, I contacted Dr. Ingrid Olson, at the University of Pennsylvania, about the possibility of a summer research internship, as I saw that her field of research coincides with my scientific interests. Dr. Ingrid Olson works in the field of cognition, specifically using fMRI andTMS to research visual cognition and the effects of bottlenecks imposed by working memory and attention. She performs research at the Center of Cognitive Neuroscience at the University of Pennsylvania.

The topic of hypnopaedia was brought up during a discussion with Dr. Olson about research possibilities. Dr. Olson had been interested in doing research about learning while sleeping, and I suggested the possibility of testing whether simple words can be learned during sleep. Once the research topic was established, I searched for articles about hypnopaedia, and found that there were conflicting conclusions to studies of the 1950's, and that the topic was

abandoned for the most part due to a study which claimed that hypnopaedia was impossible, as well as claiming faults in the previous studies on hypnopaedia. While reading this article, I noticed a number of faults in the setup of the experiment, which indicated the possibility that hypnopaedia was not impossible. The paper of the research, done by Emmons and Simon, never specified the nouns used in the study, so their results couldn't be duplicated. The words in the study were learned by listening, but volunteers were tested in a written format. The fact that the words chosen were already known by the subjects, and therefore, were not "learned ", only heard, was an overlooked flaw. Finally, bulky EEG machines monitored sleep and may have interfered with sleep quality. In spite of this, the Emmons and Simon study successfully convinced the western world that hypnopaedia was not viable.

In order to properly analyze the statistics of my study, I had to learn new mathematics. Microsoft excel was a useful tool for examining data, but I still needed to use and understand T-tests and the significance of the result of T-tests. T-tests were a key part of this study and are figured out by a formula which takes the mean, standard deviation, and number of data points into account in order to show significance in variants of two sets of data. I had to apply a T-test to data of both subjects and controls in order to see statistically if the data was significant or not. There was a good amount of graph analysis in this project, where the graph produced by the Actigraph needed to be analyzed for sleep disturbances. I also used averages for many different aspects of analyzing data, such as to determine the extent of which the stimuli were learned during sleep by all the subjects.

Science definitely became more alive to me due to my project. The research I did necessitated detailed knowledge of sleeping stages and helped me learn about the theories behind the amazing processes which occur in our brains during sleep. Knowledge of sleep stages was needed in order to determine when to play the audio DVD during sleep. The stimuli needed to be played in the part of sleep when the subject was still partly conscious, otherwise the subject might not hear the stimuli. Math also became more alive, as all the different formulas and equations worked towards the common goal of displaying information for analysis. Math conveyed many trends in the data; Irregularities could be singled out which allowed me to understand why the irregularity was present. The practical uses of science and math in my research made it much easier for me to grasp what I considered formerly to be abstract ideas and use them to aid my research.

In all truth, the research process was not easy for me. There was a lot of legwork involved for the testing of subjects, asking people to participate in the project, and a lot of work to compile the results. Each day I would have to test someone, administer a 24 hour test to someone else, and explain to a new volunteer how to work the equipment for that night while entering data from the other two subjects. However, when looking back on the whole experience, it feels truly rewarding to be able to say that it was my efforts which brought about this new discovery to science. Many times during even high school research, you are dealing with extremely important topics, where your innovativeness can make a difference. Your discoveries can be extremely important to the world at large, and change a field of science significantly. Do what interests you, as you will be passionate about your research and therefore persist and succeed.

Part II: Research

Introduction

One third of a human's life is spent sleeping which, while it is undoubtedly a necessary part of daily life, seems like a waste of precious hours in today's multi-tasking, do-everything society. What if you could maximize even your shut-eye time by learning while sleeping? Is that not the answer to every last-minute cramming student's prayer?

The subject of Hypnopaedia, or learning during sleep, first appeared in Aldous Huxley's 1932 novel, Brave New World. In the novel, the concept of sleep-learning is born when a Polish boy named Reuben Rabinovitch recites a radio broadcast in English after having heard it in his sleep. Although Reuben did not comprehend what he had learned via hypnopaedia, the event spurred government officials in the story to utilize hypnopaedia as a method of inculcating morality into the populace while they slept.[1]

This fictional idea spawned actual research in this field in the 1950's, and many studies were done to verify whether sleep-learning was actually possible. One notable experiment by L. LeShan attempted to cure nail-biting in children. A record was played with fifty repetitions of the sentence, "my fingernails taste terribly bitter". This recording was played six times a night for 54 successive nights to an experimental group of 20 children. At the conclusion of the experiment, 100% of the 20 control subjects still bit their nails, while 40% of the experimental volunteers had kicked the habit.[2]

A different study conducted by B. Fox and J. Robbin attempted to determine whether people could learn foreign words in their sleep. They first taught each subject 15 Chinese words while they were awake and tested to see how many of the Chinese words the subjects learned. They then gave the subjects an audio machine for the night which kept repeating 25 Chinese words, all different from the first test. The subjects were tested the morning after to see if they

could recall the meanings of the 25 new Chinese words and concluded that the subjects did indeed learn the words and were able to correctly identify their English translations the next day, though the subjects did not score as high as they did on the 15 words learned while awake.[3]

Unfortunately, each of these experiments had a flaw that gave some doubt to their credibility. The LeShan experiment did not investigate the personalities of the children thoroughly[4]. The subjects were also not re-examined later to see if breaking the nail-biting habit was long-lasting or just temporary. The study done by B. Fox and J. Robbin did not see how efficiently the words were learned and did not carefully monitor the sleep quality of their subjects.[4]

In the 1960's, hypnopaedia was deemed impossible due to claims from W. Emmons and C. Simon. Their experiment had a list of 10 one-syllable nouns repeated to nine subjects while sleeping. The next day, subjects were given a test where they were told to visually select the words they had heard overnight from a printed list of 50 nouns. The subjects selected words at chance level and did not do much better than the control subjects.[5] However, the Emmons and Simon paper had major flaws in it, which I explain above, in the personal section. The flaws were not addressed at the time, and the scientific community fully trusted the study, causing interest in the field to dwindle among western scientists.

Hypnopaedia, however, was further explored in Russia, where quite a few experiments were producing interesting results. The works of Hoskovec in 1966 and Rubin in 1968 and 1971 suggested that people were capable of learning during sleep, though the learning was of a simpler nature. A possible reason that results differed between the Russian and the Western studies was that the protocol used in the Russian studies tested on the basis of recognition instead of recall. Details of the study are difficult to obtain here, however, because the research cannot be found in translation. Despite the Russian findings, news of the experiments failed to

change the attitude that many western scientists had towards hypnopaedia. The topic fell into obscurity in the West with the belief that it was impossible to achieve[6].

The goal of this research project is to resolve the issue of the possibility of sleep- learning since, to date, no one has been able to definitively prove whether or not it is possible. This experiment employed implicit learning, which occurs when people are subjected to certain information and learn just by being exposed to it. If the subject is simply exposed to the stimuli during REM sleep and the initial two stages of sleep, however, the subject's consciousness level may be high enough to actually learn the stimuli.

In order to do a study on sleep, one must understand its stages. Sleep is divided into two different parts, REM sleep and non-REM sleep. Non-REM sleep comes first and is composed of four stages of sleep, which accounts for 75-80% of all sleep. In Stage One sleep, the muscles become more relaxed and consciousness decreases, while Stage Two sleep continues decreasing consciousness and awareness and accounts for 45-55% of sleep. Stage Three sleep is a slow wave sleep and serves as a transition from Stage Two to Stage Four. Stage Four sleep is known as Delta sleep, the deepest stage, from which it is difficult to wake up. Stage Four sleep is followed by REM sleep, the period where dreaming occurs. These cycles repeat continuously throughout the night[7]. To conduct a hypnopaedia study, it would be impractical to try and have someone learn during Stages Three or Four sleep since the state of consciousness during these intervals is probably too deep to be affected by external stimuli. Thus, the ideal stages to hear the stimuli would be Stages One, Two, and REM sleep.

Problem

Can people maximize the time they spend sleeping by learning as well?

Hypothesis

People can learn simple words in their sleep and be able to identify them the next day.

Materials & Methods

This research project is divided into several segments:

Part I. The stimuli used in this experiment are based on those used in Dr. Jenny Saffran's experiment on infant learning. The stimuli Dr. Saffran created mimics word structure and letter combinations in real words, without being actual words, as well as the fact that they had never been heard by subjects prior to the examination, which makes it possible to deduce whether or not the subjects actually learned the stimuli, as they could not possibly have known them from any other source. These were chosen for their simplicity, since they might be easy enough to learn during sleep. The first set of experiments examined the ability of a person to differentiate between these 3-syllable nonsensical words played while they were asleep and "foils", which are similar words that were not recorded on the audio file. The subjects were tested verbally the morning after the stimuli were played. The ability to differentiate between one stimulus and one foil, (and choose the stimulus), was tested. There were two groups of test subjects in this segment. The "A" group (16 subjects) was tested without determining the quality of their sleep during the night; the "B" group (22 subjects) had the quality of their sleep assessed by wearing an Actigraph to sleep to ensure that they were indeed sleeping while the audio file played the words.

Part II. The second segment investigated the volunteer's ability to differentiate between the stimuli and the foil words 24 hours after the initial test to determine if there is longer-term recall. In addition, there were six questions offering three choices, one stimulus and two foils, to reduce the chances of "guessing" a correct answer, thereby replacing the 50% chance with a 33% chance.

Part III. The third segment tested the ability to actually learn Italian words and their English definitions while sleeping versus a set of control Italian words and their definitions that were not played during the sleep period. Volunteers were tested the morning after playing the DVD, as well as 36 hours after playing the DVD, to compare the amount of recall between the two time periods. A control group who did not hear the DVD was tested as well.

Methods Part I: Stimuli were created based on the words used by Dr. Jenny Saffran.

Stimuli	Foils
Babupu	Batipa
Bupada	Bidata
Dutaba	Dupitu
Patubi	Pubati
Pidabu	Tipabu
Tutibu	Tapuba

The first audio band played is a volume test which allows the subject to adjust the volume to a level that he would be comfortable playing while asleep. The volume test, which is set at the same volume as the stimuli heard later on, was done so as not to have the subject consciously hear any of the stimuli, as well as to prevent any light sleepers from waking up during the audio segment. An hour of silence follows the audio test in order to allow the subject to fall asleep and, more importantly, to ensure that the subject never consciously hears the audio. If the subject is still awake by the time the hour of silence is completed, he could reset the audio and repeat the hour of silence to allow more time to fall asleep before the audio is presented. The stream of audio stimuli which follows lasts a full two hours.

An audio-test was administered to the subjects the following morning to determine if, and what, the subjects had learned. There were six stimuli and six foils, resulting in 36 trials in total in order to test each foil with each stimulus. For the audio testing sequence, Matlab randomized the 36 trial sequences. The subjects were then instructed to select the word that seemed more familiar to them, or to select the word that they might have heard before. There were two versions of the test sequence made, and one was chosen at random before testing a subject.

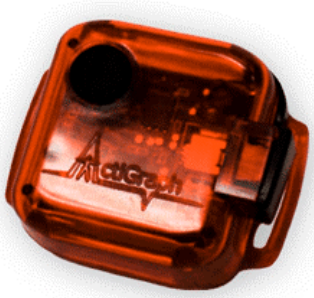


Fig. 1. Actigraph, www.theactigraph.com

In study A, 16 subjects were given an audio DVD of the stimuli and its compatibility with their computer was confirmed. The subject was given instructions on how to adjust the volume on a test audio track in order to set it at a level that they would be comfortable sleeping with at night. The subjects did not use headphones; the computer's speakers broadcast the audio. All the subjects were tested before 11 AM on the following morning. Testing was conducted by subjects listening through headphones and selecting which clip sounded more familiar as the experimenter recorded their selection. The subject faced away from the experimenter for the test sequence.

Study B is similar to Study A, but in Study B sleep efficiency was monitored in order to confirm that the subject never consciously listened to the audio. To do so, the subjects were given an Actigraph wrist device to wear while they slept, as well as the DVD to listen to. The Actigraph evaluates sleep efficiency and, more importantly, monitors whether or not the person was sleeping while the stimuli were being heard. All subjects had more than 85.54% sleep efficiency, indicating that there were minimal sleep disturbances.

A further extension of this project was to devise a test to see if real words and their definitions could be learned while asleep. In order to do this, 12 obscure Italian words and their definitions were obtained**. Six words and their English definitions were recorded on a DVD and repeated for an average of 235 times, creating a total of 2.04 hours of stimuli, while the other six were not recorded, to be used as internal controls and included in the verbal test administered to the subjects. During the testing, there was *no prior indication* to the test subjects as to the fact that some words on the test were on the audio and other words were *not*.** The words were recorded with a 3-second pause in between so as to allow the brain to associate the word and its English counterpart as a unit. The new stimuli were randomized using iTunes software. The subjects also wore the Actigraph to monitor sleep quality.

Italian test words

The underlined words are the true definitions. The red words are definitions that were recorded on

the DVD, while the black print definitions were never heard on the DVD. The bold words are the Italian words recorded on the DVD. Italian words not in bold were not recorded. After testing the volunteer, it was then noted:

1) How many recorded words are correct

2) How many non-recorded words are correct

3) How many times recorded definitions were chosen for the recorded words incorrectly

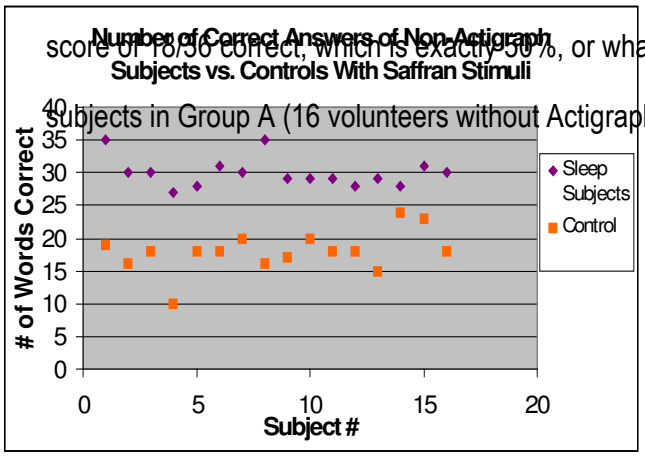
4) How many times the recorded definitions were chosen for the non-recorded words

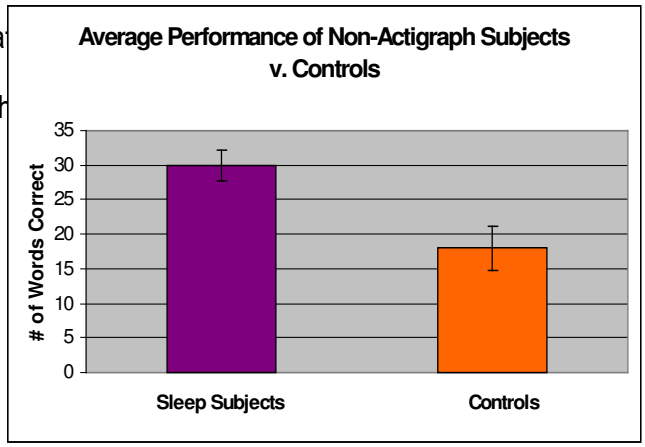
1) Agrume	*bishop*	citrus	slang
2) **Portamazze**	*caddy*	negotiable	*howl*
3) **Spillo**	*ditch*	wax	*pin*
4) Cera	wax	*braid*	cork
5) **Fosso**	*caddy*	*ditch*	plum
6) Sughero	*howl*	slang	cork
7) Susina	*pin*	plum	negotiable
8) **Urlo**	*howl*	citrus	*pin*
9) **Vescovo**	*braid*	*bishop*	wax
10) Tratt a bile	negotiable	plum	*ditch*
11) Gergo	slang	*caddy*	cork
12) **Treccia**	wax	*bishop*	*braid*

Results & Discussion

Part I: The control group (those who did not listen to the DVD while sleeping) averaged a score of 16/30 correct, which is exactly 50%, or wha

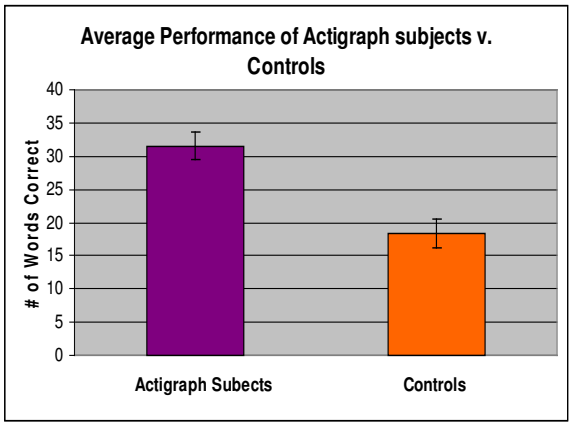
subjects in Group A (16 volunteers without Actigraph

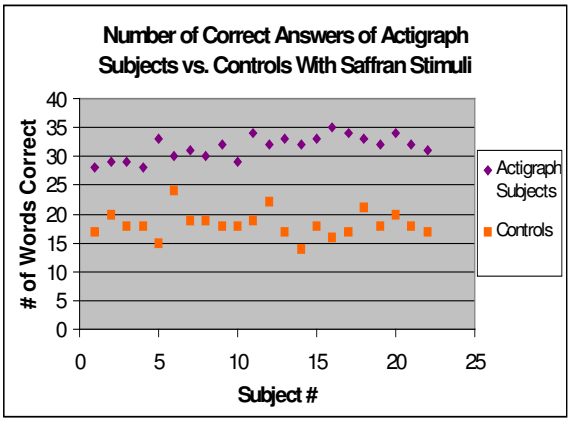




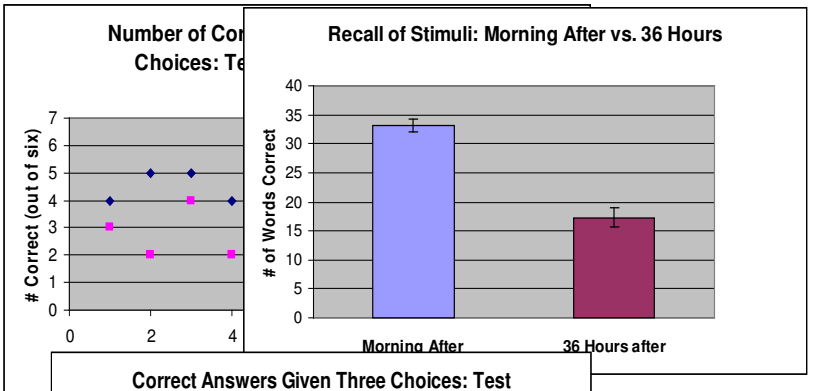
36 words tested (standard deviation 2.1) displaying 83% accuracy. While this group was not monitored during sleep, the data suggests people can still learn during their normal sleeping time.

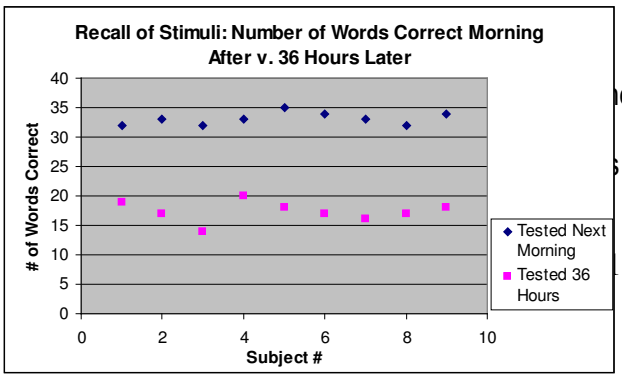
Subject Group B (who wore Actigraphs while sleeping) averaged a score of 31.5 / 36 words correct (std dev 2.1), an accuracy of 88%. The actigraph subjects displayed minimal movement during the duration of the stimuli, averaging a sleep efficiency of 91.33%.

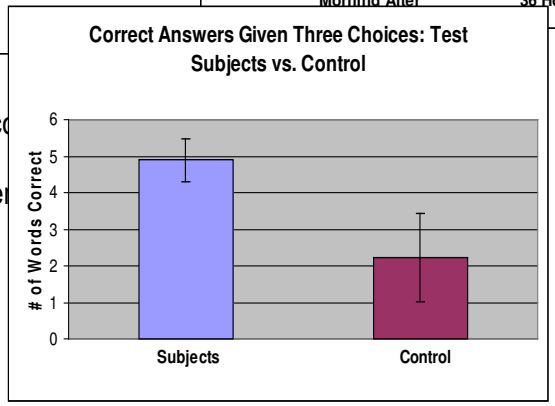




Part II: On the test segment that offered three answer choices for each question, subjects correctly selected an average of 4.9 / 6 (std dev 0.6), displaying 80% accuracy. The controls averaged 2.3 / 6 words correct (std dev 1.2), showing 38% accuracy. These statistics indicate that even with a 1 out of 3 (33%) chance of accuracy, the subjects could properly identify the stimuli with 80% accuracy.







subjects scored an average of 33.1 / 36 (std dev 1.1) when tested the morning after listening to the stimuli; an accuracy of 92%. When tested 36 hours after the exposure to the stimuli, the subjects scored an average of 17.3 / 36 correct (std dev 1.7), reduced to an accuracy of 48% correct.

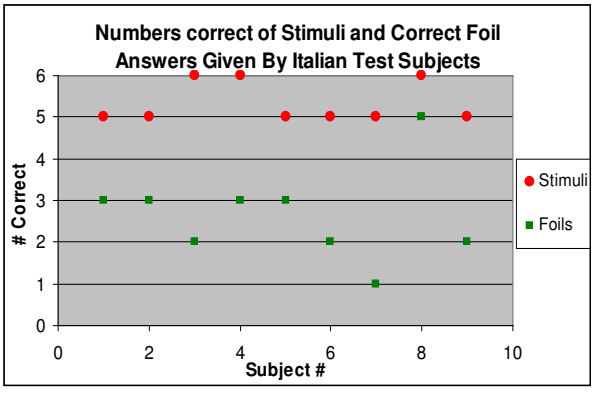
This shows decreased retention of the stimuli after a 36 hour time period, suggesting that the learning of the Saffran words is only short-term.

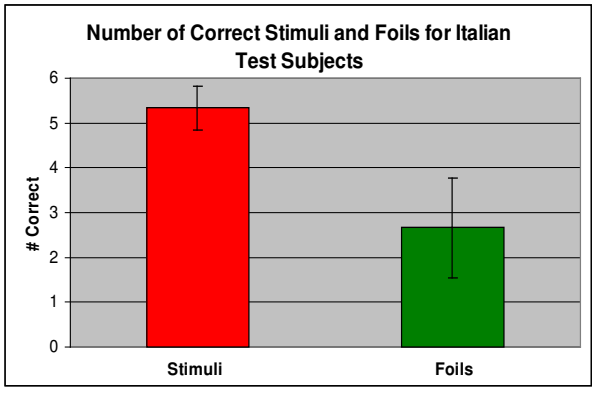
Part III: The Italian portion of the experiment tested two different aspects:

1) The number of Italian stimuli words the subjects correctly defined.
2) The number of Italian foils the subjects correctly defined.

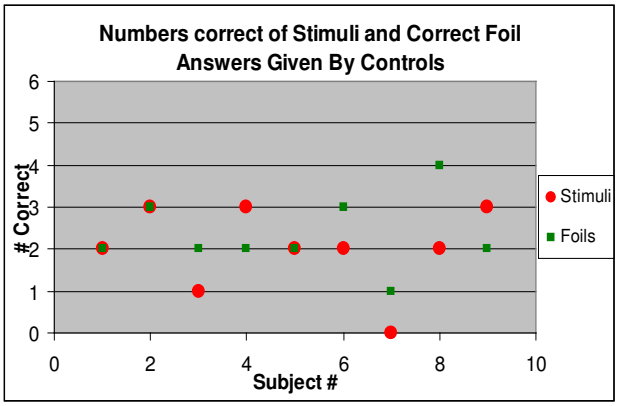
In addition, a control group that did not listen to the Italian word DVD was given identical tests and results were similarly tabulated. There were nine test subjects in total in this section as well as nine controls. The test subjects wore an Actigraph during the night, which indicated an average of 92.51% sleep efficiency.

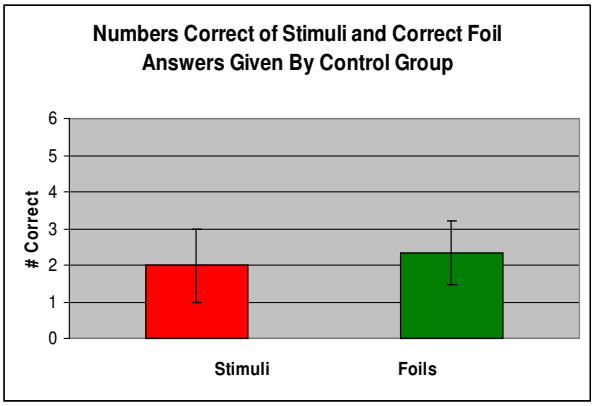
Test subjects averaged 5.3 / 6 (std dev 0.5) correct definitions of stimuli Italian words; an accuracy of 88%, while their accuracy of defining foil Italian words that they did not hear while sleeping was only 2.4 / 6 (std dev. 0.7), creating an accuracy of only 40%, close to random chance.



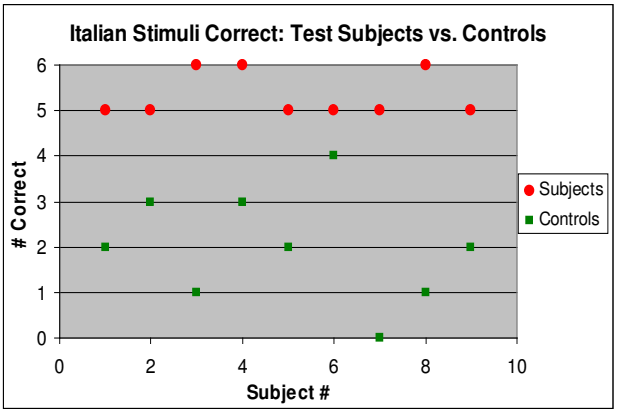


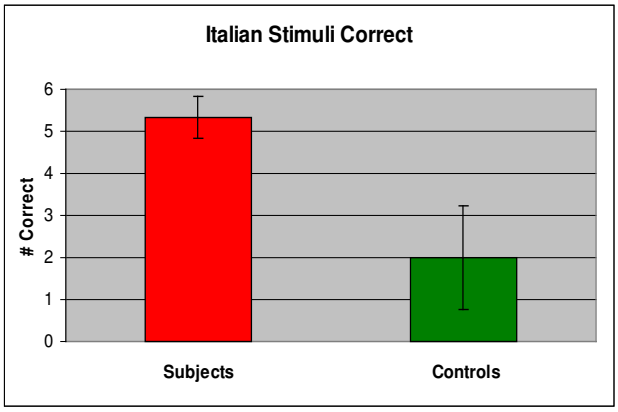
The control group answered, on average, 2 / 6 (std dev 1.2) correct stimuli Italian words; (33% accuracy) and 2.3 / 6 (std dev 0.9) correct foil words; thus, with 38% accuracy. This indicates that there was no significant difference in the accuracy of the control group between the stimuli



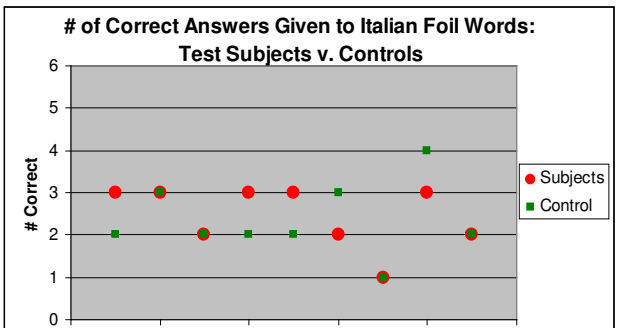


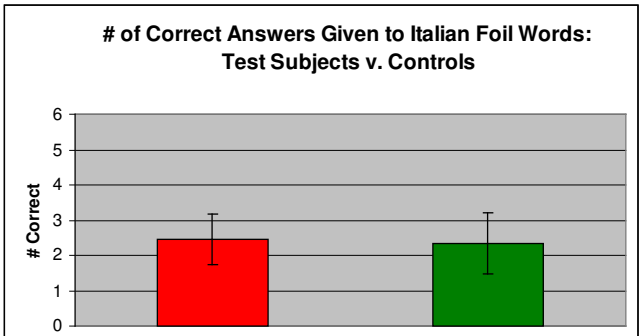
words and the control words, ***while the accuracy of the test subjects for stimuli words was <u>double</u> that of the control foil words***. ***In addition, the accuracy of the test subjects for the stimuli words was more than <u>double</u> that of the control group (did not listen to the DVD) .*** However, **there was no difference between the subject group and the control group in their accuracy in defining the Italian foil words.**



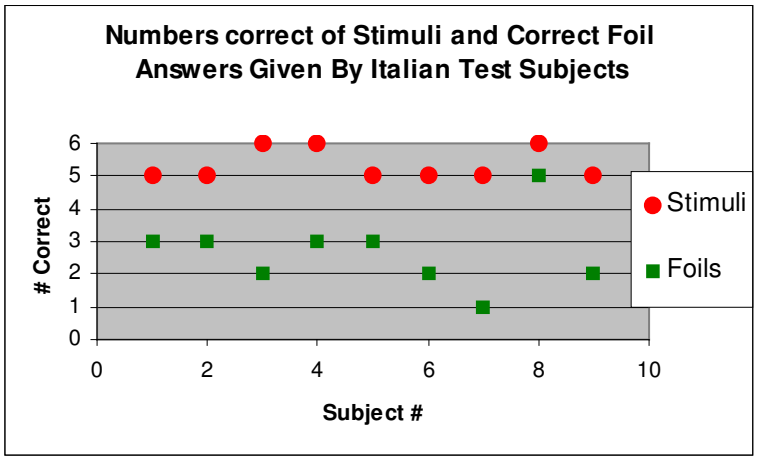


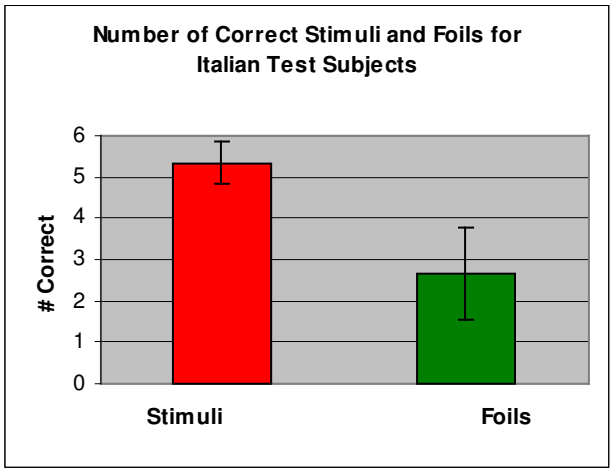
These findings strongly suggest that the test subjects learned the English definitions of six obscure Italian words while they were sleeping, while they guessed incorrectly as poorly as the control group on the foil words.



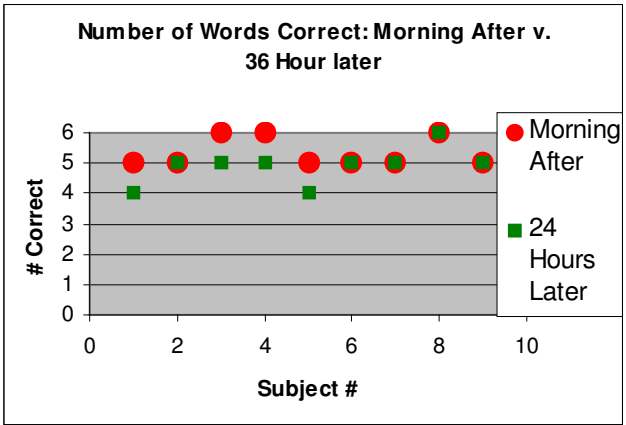


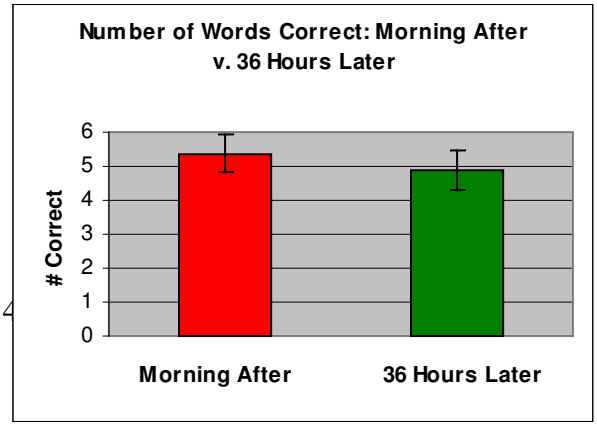
Three answer choices were used during the oral exam in order to make sure subjects didn't pair wrong definitions to Italian words. There were two English definitions from the list they heard during the night and one choice was a word that was not on the DVD per trial. Thus, if they chose the correct definition from a choice of two DVD words (and one that was not on the DVD), it would indicate that they actually associated the correct definition with its Italian word and did not select it simply because they had heard it on the list and chose it for its familiarity.





Longer-term recall was tested with the Italian word subjects 36 hours after they slept with the DVD playing. **Here, 36 hour recall was far better than the Saffran words; 4.8 / 6 (std dev 0.6) correct, giving 80% accuracy as opposed to 48% accuracy with the Saffran words.**





This indicates that the quality of learning the Italian words while sleeping is superior to that of learning the Saffran words.

Conclusions

A summary of the results of this study appears in the following table, along with a student's t-test to show validity of results (t-test<0.05):

		Saffran Stimuli	Actigraph-Saffran	3-choices	Retention 36 hrs	Italian Stimuli correct	Italian Foils Correct	Italian36hr Retention
Test Subjects	Average # Correct	29.9	31.5	4.8	17.3	5.3	2.4	4.9
	% Correct	83%	86%	80%	48%	88%	40%	81%
	Range of Answers	27-35	28-35	4-6	14-20	5-6	1-3	4-6
Control Subjects	Average # Correct	18	18.3	2.2	17.3	2	2.3	2.3
	% Correct	50%	51%	36%	48%	33%	38%	38%
	Range of Answers	10-24	14-24	0-4	12-22	0-4	1-4	1-4
	t-test	3.52E-13	1.69E-23	2.0E-05	8.71E-14	1.15E-06	7.72E-01	1.86E-06

The first part of this study strongly suggests that people can learn simple word structure while asleep with 86% accuracy, versus 50% (chance guessing) of a control group. Testing with two foils and one stimulus, which reduced the chances of guessing correctly, further emphasized this learning, with the test group still choosing 80% correct answers as opposed to 38% by the control group. The test group, however, exhibited a marked decrease in the number of correct Saffran words when retested 36 hours later, with only 48% accuracy, or random choice. Perhaps this is because once the subjects were exposed to the foils during the first audio test, the

unfamiliarity aspect the Saffran foils previously had was reduced or eliminated altogether. This would mean that when presented with the test for a second time, subjects would have greater difficulty selecting the correct choice, as they had become familiar with both foils and stimuli. Or, it may be that since the words were nonsensical, they formed no association in the brain and therefore reduced long-term memory.

By using Italian words that were obscure, the third portion of this experiment tested the ability to learn actual words. The results of Italian words and their definitions as stimuli indicate that **hypnopaedia has a practical application in society, as subjects were able to not only *learn* (88% accuracy versus 40% of the control group), but *retain* the practical material presented during sleep, still displaying 80% accuracy when tested again after 36 hours.**

A possible reason the Italian words were retained longer than the Saffran stimuli is that the Italian study focused on the brain associating two words together, while the Saffran part focused on the learning of the words. The bond forged by the brain between the Italian words and their English counterparts seems to have imprinted better than the learning of individual words.

One observation noted during Part III of the study was that the subjects had an instant recall of Italian words. When presented with a stimulus, subjects seemed to immediately reply with the utmost confidence that the answer was correct. When presented with a foil word, however, the subjects hesitated before selecting a choice, and were unsure of their selected answer. This could be a clear indication of the success of the imprinting process with word association. There was no prior indication that some words on the test were in the audio and other words were not.

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